Supplementary Information of

Cobalt-catalyzed oxidation of the β-O-4 bond in lignin and lignin model compounds

Torsten Rinesch[†] and Carsten Bolm[*,†]

[†] Institute of Organic Chemistry, RWTH Aachen University, Landoltweg 1, 52074 Aachen, Germany.

E-mail: carsten.bolm@oc.rwth-aachen.de

TABLE OF CONTENT

1. General

1.1. Materials and methods

All reagents were acquired from commercial suppliers and used without further purification. THF was dried by distillation over Solvona® (sodium on molecular sieves) in the presence of benzophenone. DCM, MeOH, EtOAc and dioxane were purified by distillation over boiling chips. Thin-layer chromatography (TLC) analysis was performed using Merck silica gel 60 F254 TLC plates, visualized by UV light irradiation (254 nm). Flash column chromatography was carried out with silica gel 60 (35-70 mesh). Catalytic reactions were carried out in a 51.10201.0000 Büchi "tinyclave steel" type 1/25 mL autoclave. Kraft-lignin sample **A** was directly purchased from Sigma Aldrich (#370959, CAS: 8068-05-1), whereas lignin sample **B** was supplied by the "Fraunhofer-Zentrum für Chemisch-Biotechnologische Prozesse" (CBP) Leuna, Germany, using the organosolv method on beech wood as biomass feedstock by working with ethanol/water mixtures at elevated temperatures and pressures.

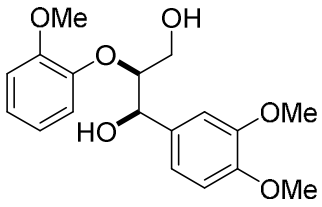
1.2. Instruments

NMR spectra were recorded on a Varian Inova 400 (^{1}H NMR: 400 MHz, ^{13}C NMR: 101 MHz) or Agilent VNMRS 600 (^{1}H NMR: 600 MHz, ^{13}C NMR: 151 MHz) spectrometer. Chemical shifts (δ) are given in ppm relative to the residual solvent peak ($CDCl_3$: δ = 7.26 ppm (^{1}H NMR), 77.1 ppm (^{13}C NMR); DMSO-d_6: δ = 2.50 ppm (^{1}H NMR), 39.5 ppm (^{13}C NMR)). Spin-spin coupling constants (*J*) are given in Hz. Mass spectra were recorded on a Finnigan SSQ 7000 spectrometer (EI,CI) and HRMS on a Finnigan MAT 95 spectrometer (ESI). Abbreviations are as follows: s (singlet), d (doublet), t (triplet), m (multiplet), dd (doublet of doublets), ddd (doublet of doublets of doublets), td (triplet of doublets), bs (broad singlet). HPLC measurements were conducted on an Agilent Infinity 1260 HPLC apparatus using an Agilent Eclipse XDB-C18 (4.6 mm ID x 250 mm, 5 μm) column. H_2O/MeOH (60:40) as eluent and a flow rate of 1.0 mL/min was used.

2. Synthesis of lignin β-O-4 model compounds

Lignin model compounds (**1a-b** and **1d-h**) used in the corresponding oxidation reactions were prepared according to the procedure described by Bolm *et al.*.[1] Monolignol **1c** was obtained through a three step procedure. The first two reaction steps being in accordance to the procedure by Picart *et al.*.[2] The final step displays a modified procedure by Bolm and co-workers.[1]

erythro-1-(3,4-Dimethoxyphenyl)-2-(2-methoxyphenoxy)propan-1,3-diol (1a)



$C_{18}H_{22}O_6$ (334.37 g/mol)

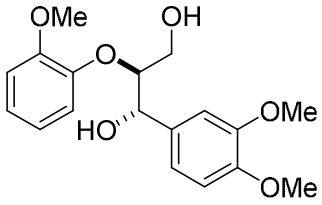
^{1}H NMR (400 MHz, ($CDCl_3$)): δ = 7.07 (ddd, *J* = 8.2, 7.2, 1.8 Hz, 1H), 6.99–6.89 (m, 5H), 6.84 (d, *J* = 8.3 Hz, 1H), 4.99 (d, *J* = 4.7 Hz, 1H), 4.16 (ddd, *J* = 6.0, 4.7, 3.4 Hz, 1H), 3.92 (m, 1H), 3.89 (s, 3H), 3.88 (s, 3H), 3.87 (s, 3H), 3.66 (dd, *J* = 12.1, 3.4 Hz, 1H), 2.79 (bs, 1H).

^{13}C NMR (101 MHz, ($CDCl_3$)): δ = 151.7, 149.1, 148.6, 147.0, 132.5, 124.4, 121.8, 121.2, 118.5, 112.3, 111.1, 109.3, 87.6, 72.8, 60.9, 56.0 (3C).

MS (EI, 70 eV): *m/z* (%): 334 (31) $[M]^+$, 167 (16), 166 (12), 151 (17), 150 (100), 139 (20), 124 (11), 121 (12).

The spectral data corresponds to the one reported in literature.[1]

threo-1-(3,4-Dimethoxyphenyl)-2-(2-methoxyphenoxy)propan-1,3-diol (1b)



$C_{18}H_{22}O_6$ (334.37 g/mol)

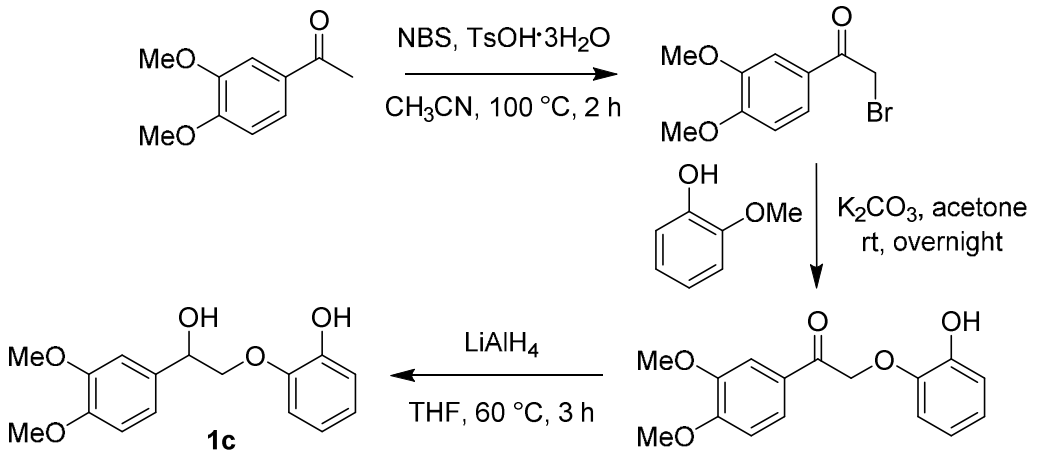
^{1}H NMR (400 MHz, ($CDCl_3$)): δ = 7.13 (dd, *J* = 8.0, 1.6 Hz, 1H), 7.07 (ddd, *J* = 8.0, 7.2, 1.6 Hz, 1H), 7.01–6.96 (m, 2H), 6.95 (dd, *J* = 8.0, 1.6 Hz, 1H), 6.93 (ddd, *J* = 8.0, 8.0, 1.6 Hz, 1H), 6.85 (d, *J* = 8.0 Hz, 1H), 4.99 (d, *J* = 4.7 Hz, 1H), 4.03 (dt, *J* = 7.7, 3.7 Hz, 1H), 3.91 (s, 3H), 3.88 (s, 3H), 3.87 (s, 3H), 3.69 (bd, *J* = 1.6 Hz, 1H), 3.63 (dt, *J* = 12.0, 3.7 Hz, 1H), 3.48 (ddd, *J* = 12.0, 7.7, 3.7 Hz, 1H), 2.72 (dd, *J* = 7.7, 4.7 Hz, 1H).

^{13}C NMR (101 MHz, ($CDCl_3$)): δ = 151.5, 149.2, 149.1, 147.7, 132.2, 124.5, 121.9, 121.2, 119.8, 112.3, 111.2, 110.0, 89.7, 74.1, 61.2, 56.0 (3C).

MS (EI, 70 eV): *m/z* (%): 334 (30) $[M]^+$, 167 (15), 166 (12), 151 (17), 150 (100), 139 (20), 124 (11), 121 (12).

The spectral data corresponds to the one reported in literature.[1]

1-(3,4-Dimethoxyphenyl)-2-(2-methoxyphenoxy)ethan-1-ol (1c)



$C_{17}H_{20}O_5$ (304.34 g/mol)

A dry 250 mL three-necked flask equipped with a reflux condenser, an argon inlet, a dropping funnel and a magnetic stirrer was charged with $LiAlH_4$ (16.5 mmol, 0.63 g, 1 eq.) in dry THF (45.0 mL) and cooled to 0 °C. 1-(3,4-dimethoxyphenyl)-2-(2-methoxyphenoxy)ethan-1-one (16.5 mmol, 5.00 g, 1 eq.) was dissolved in dry THF (60 mL) and added dropwise over 15 min at 0 °C. The resulting solution was heated to 60 °C and stirred for 3 h. Then, the reaction mixture was cooled to 0 °C and quenched by the sequential and dropwise addition of water (0.65 mL), aqueous NaOH solution (15 % w/w, 0.65 mL) and additional water (1.95 mL). Upon completion the reaction mixture was stirred for 1 h at room temperature. It was filtered over celite, washed with DCM (150 mL), dried over $MgSO_4$, and the solvent was removed under reduced pressure. The product was purified by column chromatography (pentane/EtOAc, 1:1) and **1c** was obtained as a colorless solid (4.07 g, 82%).

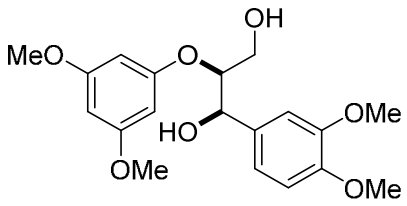
^{1}H NMR (400 MHz, ($CDCl_3$)): δ = 7.03–6.88 (m, 6H), 6.86 (d, *J* = 8.2 Hz, 1H), 5.05 (dd, *J* = 9.4, 2.9 Hz, 1H), 4.17 (dd, *J* = 10.0, 3.0 Hz, 1H), 3.97 (t, *J* = 9.4 Hz 1H), 3.90 (s, 3H), 3.89 (s, 3H), 3.88 (s, 3H), 3.44 (bs, 1H).

^{13}C NMR (101 MHz, ($CDCl_3$)): δ = 150.1, 149.0, 148.7, 147.9, 132.2, 122.5, 121.0, 118.6, 116.9, 111.9, 110.9, 109.3, 76.3, 72.0, 55.9, 55.8, 55.7.

MS (EI, 70 eV): *m/z* (%): 305 $[M+1]^+$ (48), 304 $[M]^+$ (90), 288 (14), 287 (55), 181 (10), 180 (56), 168 (18), 167 (100), 164 (10), 151 (73), 149 (28), 139 (90), 138 (80), 137 (10), 124 (43), 122 (16), 121 (15), 109 (19), 108 (11), 95 (11), 77 (30), 65 (10).

The spectral data corresponds to the one reported in literature.[3]

erythro-2-(3,5-Dimethoxyphenoxy)-1-(3,4-dimethoxyphenyl)propane-1,3-diol (1d)



$C_{19}H_{24}O_7$ (364.39 g/mol)

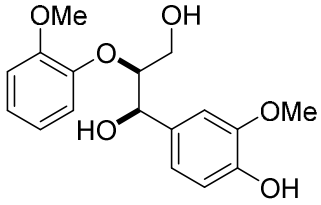
^{1}H NMR (400 MHz, ($CDCl_3$)): δ = 6.98–6.93 (m, 2H), 6.84 (d, *J* = 8.2 Hz, 1H), 6.09 (m, 1H), 6.07 (d, *J* = 2.1 Hz, 2H), 5.04 (dd, *J* = 5.3, 3.6 Hz, 1H), 4.36 (dd, *J* = 9.6, 4.7 Hz, 1H), 3.98–3.87 (m, 2H), 3.87 (s, 3H), 3.86 (s, 3H), 3.73 (s, 6H), 2.79 (bs, 1H), 2.23 (bs, 1H).

^{13}C NMR (101 MHz, ($CDCl_3$)): δ = 161.5 (2C), 159.5, 149.0, 148.7, 132.8, 118.6, 111.1, 109.4, 95.3 (2C), 94.0, 81.8, 73.9, 61.4, 55.9 (2C), 55.3 (2C).

MS (EI, 70 eV): *m/z* (%): 364 (4) $[M]^+$, 210 (30), 181 (15), 180 (100), 167 (37), 155 (25), 151 (20), 139 (31), 138 (11).

The spectral data corresponds to the one reported in literature.[1]

erythro-1-(4-Hydroxy-3-methoxyphenyl)-2-(2-methoxyphenoxy)propan-1,3-diol (1e)



$C_{17}H_{20}O_6$ (320.34 g/mol)

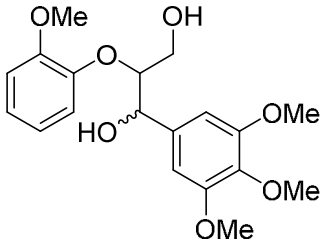
^{1}H NMR (400 MHz, ($CDCl_3$)): δ = 7,07 (ddd, *J* = 8.2, 7.2, 1.8 Hz, 1H), 6.93 (m, 5H), 6.83 (dd, *J* = 8.2, 1.8 Hz, 1H), 5.62 (s, 1H), 4.97 (m, 1H), 4.16 (ddd, *J* = 6.0, 4.7, 3.0 Hz, 1H), 3.92 (dd, *J* = 12.2, 5.6 Hz, 1H), 3.89 (s, 3H), 3.88 (s, 3H), 3.66 (ddd, *J* = 12.1 , 7.7, 3.4 Hz, 1H), 3.48 (d, *J* = 3.3 Hz, 1H), 2.74 (dd, *J* = 7.7, 5.3 Hz, 1H).

^{13}C NMR (101 MHz, ($CDCl_3$)): δ = 151.6, 146.8, 146.6, 145.1, 131.7, 124.3, 121.6, 121.1, 119.0, 114.2, 112.1, 108.6, 87.5, 72.7, 60.7, 55.9, 55.9.

MS (EI, 70 eV): *m/z* (%): 320 (1) $[M]^+$, 153 (16), 151 (15), 150 (100), 124 (15), 121 (15), 109 (17), 95 (10), 93 (19), 77 (15), 65 (15).

The spectral data corresponds to the one reported in literature.[1]

2-(2-Methoxyphenoxy)-1-(3,4,5-trimethoxyphenyl)propane-1,3-diol (1f)



$C_{19}H_{24}O_7$ (364.39 g/mol) – 5.1:1 mixture of *erythro*- and *threo*-diastereomers

^{1}H NMR (600 MHz, ($CDCl_3$), *erythro*-/*threo*-): δ = 7.12 (dd, *J* = 7.9, 1.5 Hz, 1H), 7.09–7.07 (m, 2H), 6.99–6.92 (m, 5H), 6.68 (s, 2H), 6.61 (s, 2H), 4.98 (d, *J* = 8.0 Hz, 1H), 4.96 (d, *J* = 4.6 Hz, 1H), 4.16 (ddd, *J* = 6.0, 4.7, 3.5 Hz, 1H), 4.04–4.00 (m, 1H), 3.96–3.90 (m, 1H), 3.92 (s, 3H), 3.89 (s, 3H), 3.86 (s, 6H), 3.84 (s, 6H), 3.83 (s, 3H), 3.83 (s, 3H), 3.88–3.83 (m, 1H), 3.66 (d, *J* = 11.9 Hz, 1H), 3.56 (bs, 1H).

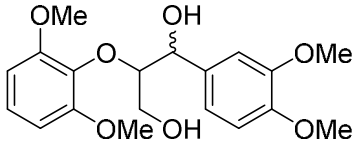
^{13}C NMR (151 MHz, ($CDCl_3$), *erythro*-): δ = 153.3 (2C), 151.6, 146.7, 137.3, 135.4, 124.4, 121.7, 121.2, 112.1, 102.9 (2C), 87.4, 72.9, 60.9, 60.7, 56.2 (2C), 55.9.

^{13}C NMR (151 MHz, ($CDCl_3$), *threo*-): δ = 153.3 (2C), 151.3, 147.4, 137.7, 135.2, 124.4, 121.7, 121.2, 112.1, 103.9 (2C), 89.4, 74.2, 61.0, 60.9, 56.2 (2C), 55.9.

MS (EI, 70 eV): *m/z* (%): 364 (27) $[M]^+$, 197 (26), 196 (87), 195 (11), 181 (12), 169 (39), 154 (14), 150 (100), 138 (17), 124 (12), 123 (10), 121 (16), 109 (19), 95 (12), 77 (13).

The spectral data corresponds to the one reported in literature.[4]

2-(2,6-Dimethoxyphenoxy)-1-(3,4-dimethoxyphenyl)propan-1,3-diol (1g)



$C_{19}H_{24}O_7$ (364.39 g/mol) – 4.6:1 mixture of *erythro*- and *threo*-diastereomers

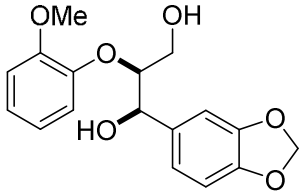
^{1}H NMR (400 MHz, ($CDCl_3$), *erythro*-/*threo*-): δ = 7.11–6.94 (m, 5H), 6.87–6.80 (m, 3H), 6.65 (d, *J* = 8.4 Hz, 2H), 6.64 (d, *J* = 8.4 Hz, 2H), 5.07 (d, *J* = 8.7 Hz, 1H), 5.03 (d, *J* = 3.2 Hz, 1H), 4.36 (bs, 1H), 4.19–4.11 (m, 2H), 3.95–3.92 (m, 1H), 3.91 (s, 6H), 3.89 (s, 3H), 3.89 (s, 9H), 3.87 (s, 3H), 3.86 (s, 3H), 3.58 (dd, *J* = 10.8, 2.7 Hz, 1H), 3.50 (d, *J* = 10.8 Hz, 1H), 3.40–3.26 (m, 2H), 3.16 (bs, 1H).

^{13}C NMR (101 Hz, ($CDCl_3$), *erythro*-/*threo*-): δ = 153.5 (2C), 153.2 (2C), 149.0, 148.9, 148.7, 148.2, 135.3, 135.0, 132.6, 132.0, 124.5, 124.5, 119.8, 118.1, 111.0, 111.0, 110.3, 109.0, 105.3 (2C), 105.3 (2C), 89.0, 87.0, 74.0, 72.5, 60.6, 60.5, 56.2 (4C), 55.9 (2C), 55.9 (2C).

MS (EI, 70 eV): *m/z* (%): 364 (6) $[M]^+$, 181 (16), 180 (100), 154 (23), 151 (17), 139 (15).

The spectral data corresponds to the one reported in literature.[5]

erythro-1-(Benzo[*d*][1,3]dioxol-5-yl)-2-(2-methoxyphenoxy)propane-1,3-diol (1h)



$C_{17}H_{18}O_6$ (318.33 g/mol)

^{1}H NMR (400 MHz, ($CDCl_3$)): δ = 6.97 (ddd, *J* = 8.0, 7.2, 1.6 Hz, 1H), 6.89 (dd, *J* = 8.0, 1.6 Hz, 1H), 6.87–6.80 (m, 3H), 6.75 (dd, *J* = 8.0, 1.6 Hz, 1H), 6.69 (d, *J* = 8.0 Hz, 1H), 5.86 (q, *J* = 1.2 Hz, 2H), 4.87 (d, *J* = 4.7 Hz, 1H), 4.05 (ddd, *J* = 6.0, 4.7, 3.7 Hz, 1H), 3.83 (dt, *J* = 12.0, 6.0 Hz, 1H), 3.79 (s, 3H), 3.57 (dd, *J* = 12.0, 3.7 Hz, 1H), 2.92 (bs, 2H).

^{13}C NMR (101 MHz, ($CDCl_3$)): δ = 151.5, 147.7, 147.0, 146.8, 133.9, 124.2, 121.6, 120.9, 119.5, 112.2, 108.1, 106.7, 101.0, 87.2, 72.7, 60.6, 55.9.

MS (EI, 70 eV): *m/z* (%): 318 $[M]^+$ (5), 151 (22), 150 (100), 124 (11), 121 (14), 109 (10), 93 (14), 65 (11).

HRMS (ESI, 70 eV): m/z calculated for $C_{17}H_{18}O_6$+Na^+: 341.0996 $[M+Na]^+$; found: 341.0999.

3. Co-catalyzed oxidation of lignin β-O-4 bonds

3.1. General procedure for the Co-catalyzed oxidation of lignin β-O-4 model compound dilignol 1a

A 25 mL glass autoclave equipped with a magnetic stirring bar was charged with dilignol **1a** (0.250 mmol, 83.6 mg), Co-catalyst and *N*-hydroxyphthalimide (amounts depending on the reaction conditions) in dioxane (depending on the reaction conditions). Next the autoclave was charged with 5 bar of O_2 and the resulting reaction mixture was stirred at the respective temperatures for the desired reaction time, followed by cooling down to room temperature. Subsequently, 20 mL of an aqueous 1M HCl solution were added and the mixture extracted with DCM (3 x 20 mL). The organic layer was then washed with 20 mL of an aqueous 1M HCl solution, brine (20 mL) and water (20 mL) and dried over $MgSO_4$. The solvent was removed under reduced pressure, followed by the addition of a standard solution (1.000 mL of 3,4-dimethoxybenzylalcohol in methanol, c = 0.2 mol/L) with an Eppendorf pipette. 1 mL of EtOAc was added and 2 samples were prepared for HPLC measurements.

3.2. General procedure for the Co-catalyzed oxidation of different lignin β-O-4 model compounds

A 25 mL glass autoclave equipped with a magnetic stirring bar was charged with the corresponding model compound **1a-h** (1.00 mmol, 1 eq.), $Co(acac)_3$ (3.6 mg, 0.01 mmol, 1 mol%) and *N*-hydroxyphthalimide (16.4 mg, 0.10 mmol, 10 mol%) in dioxane (4 mL). Next the autoclave was charged with 5 bar of O_2 and the resulting reaction mixture was stirred at 80 °C for 16 h, followed by cooling down to room temperature. Subsequently, 20 mL of an aqueous 1M HCl solution were added and the mixture was extracted with DCM (3 x 20 mL). The organic layer was then washed with 20 mL of an aqueous 1M HCl solution, brine (20 mL) and water (20 mL) and dried over $MgSO_4$. The solvent was removed under reduced pressure. The resulting products were separated using standard column chromatography (DCM/MeOH, gradient: 100:0.5 to 100:5).

3.3. General procedure for the Co-catalyzed oxidation of lignin samples A and B

A 25 mL glass autoclave equipped with a magnetic stirring bar was charged with the respective lignin sample **A** or **B** (200 mg), $Co(acac)_3$ (2.0 mg, 1 wt%) and *N*-hydroxyphthalimide (40 mg, 20 wt%) in dioxane (4 mL). Next the autoclave was charged with 5 bar of O_2 and the mixture was stirred in an oil bath at 80 °C for 16 h. At the end of the reaction time the autoclave was taken out of the oil bath and cooled down to room temperature. The remaining pressure was released and the autoclave opened. For GPC measurements the solvent was removed under reduced pressure and the solid residue was directly processed under the GPC conditions. For the respective 2D NMR HSQC measurements the solvent was removed under reduced pressure and the residue dissolved in DMSO-d_6 and filtered into an NMR tube.

4. 2D-NMR HSQC spectra for the oxidation of lignin samples A and B

All corresponding 2D NMR HSQC measurements were performed using the following specifications: d1 = 1 s, at = 0.136 s, nt = 32, aqs(F1) = 2048, aqs(F2) = 256, sw(F1) = 25.1 ppm, sw(F2) = 200 ppm., sine bell (90°) apodization-function.

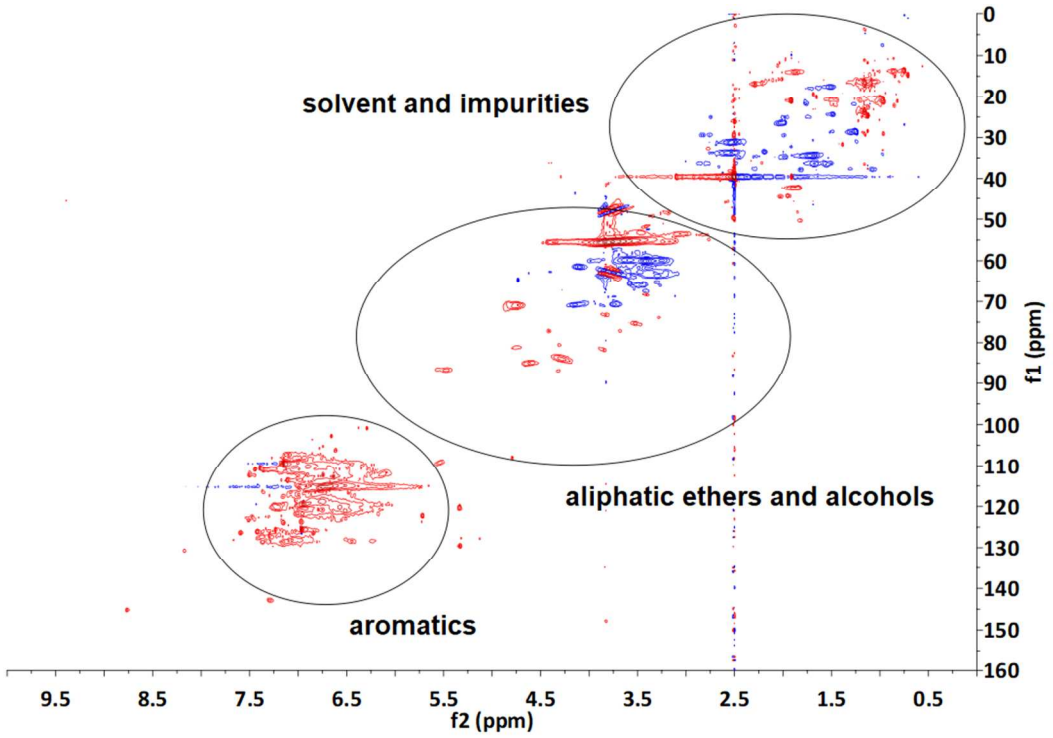


Figure S1: 2D HSQC NMR spectrum of the kraft-lignin sample A before the reaction.

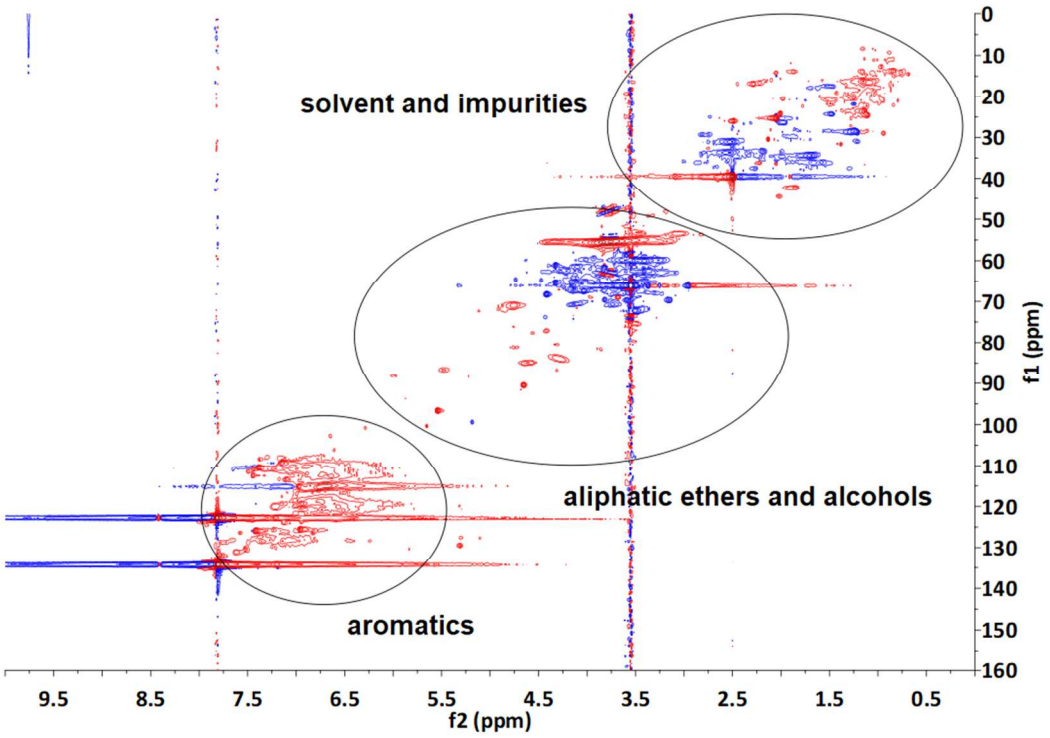


Figure S2: 2D HSQC NMR spectrum of the kraft-lignin sample A after the reaction.

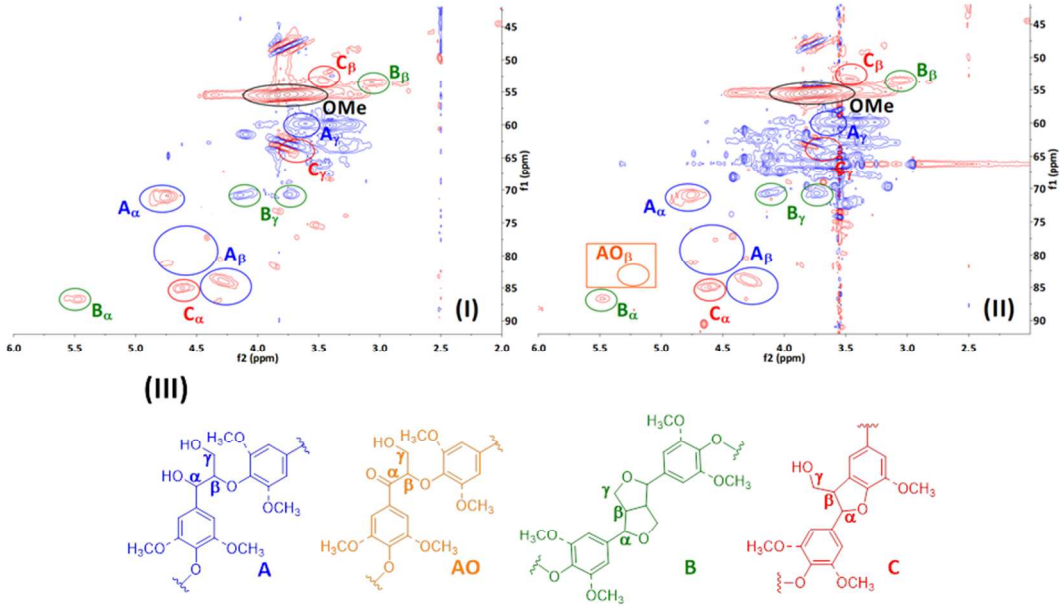


Figure S3: Aliphatic ether and alcohol region of the kraft-lignin sample A before (I) and after (II) the reaction; (III) depicts the corresponding bond motifs, labelled in the spectra as followed: β-O-4 aryl ether linkage A, A', oxidized β-O-4 linkage AO, resinol linkage B, and phenylcoumaran linkage C.

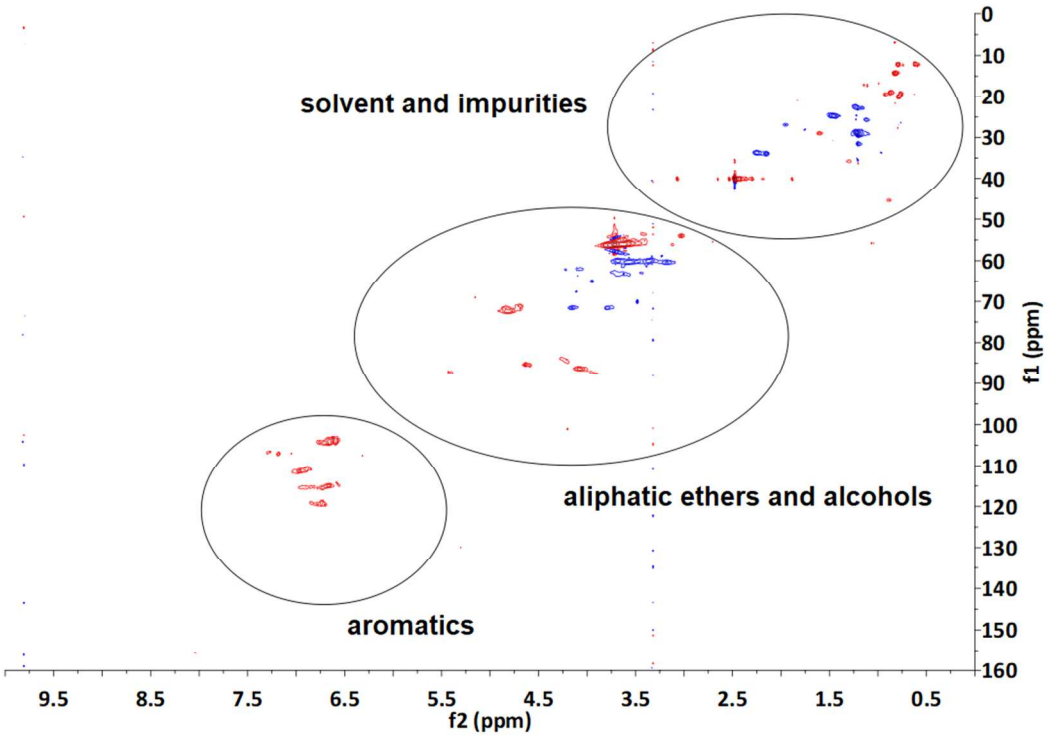


Figure S4: 2D HSQC NMR spectrum of the organosolv-lignin sample B before the reaction.

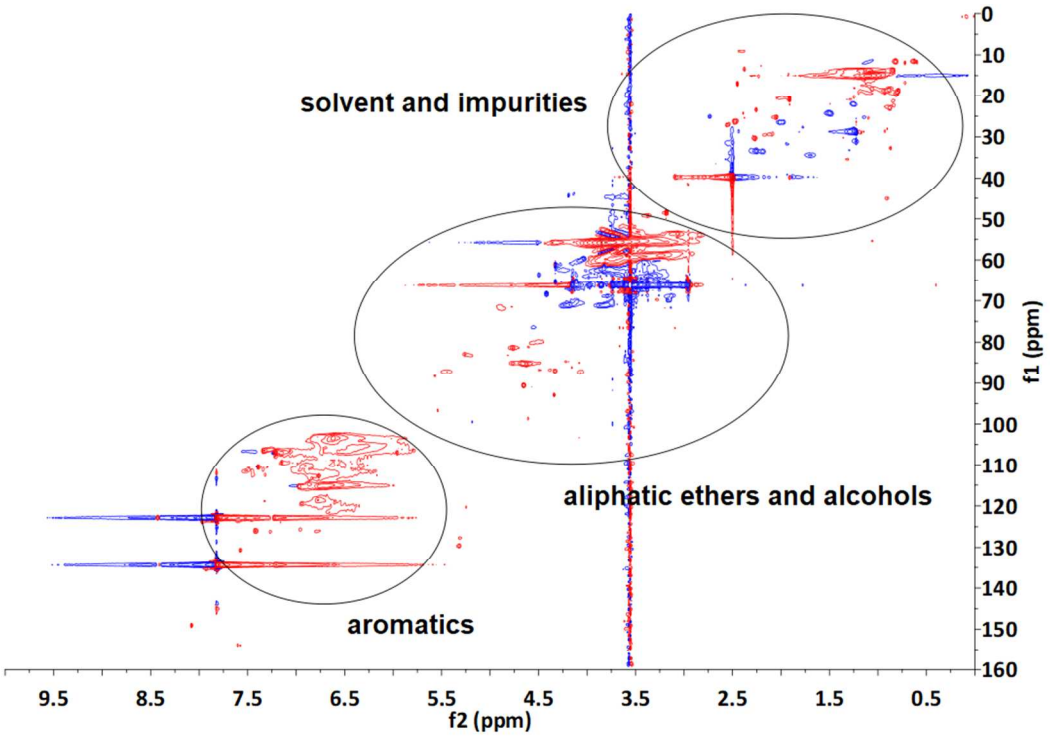


Figure S5: 2D HSQC NMR spectrum of the organosolv-lignin sample B after the reaction.

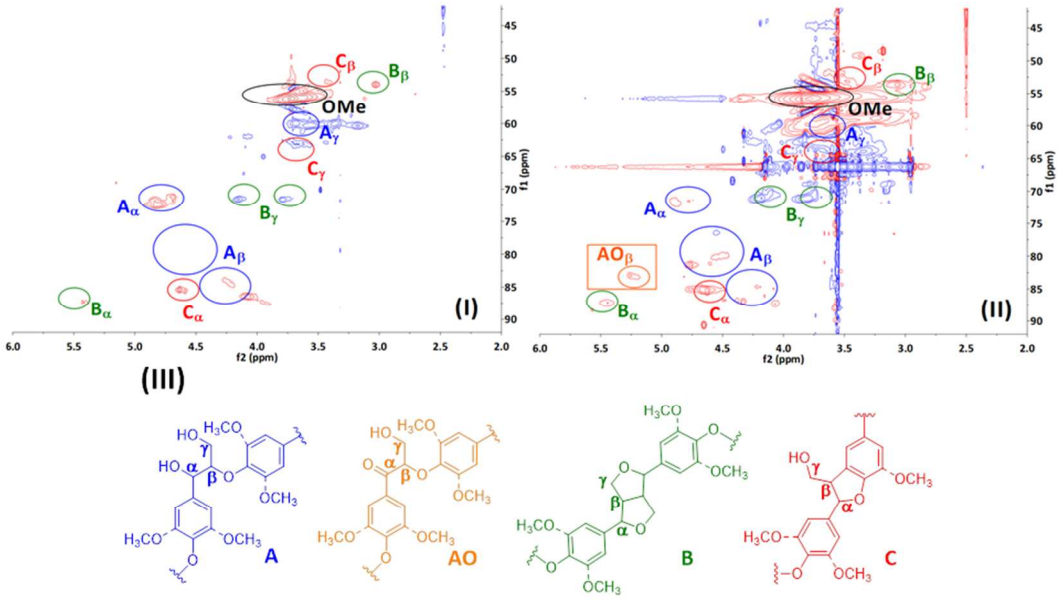


Figure S6: Aliphatic ether and alcohol region of the organosolv-lignin sample B before (I) and after (II) the reaction; (III) depicts the corresponding bond motifs, labelled in the spectra as followed: β-O-4 aryl ether linkage A, A', oxidized β-O-4 linkage AO, resinol linkage B, and phenylcoumaran linkage C.

5. GPC measurements for the oxidation of lignin samples A and B

All corresponding GPC measurements were performed on an ECO Sec System apparatus (HLC-8320GPC) from TOSOH-Bioscience LLC Company. It was equipped with one pre-column PSS Suprema (50 x 8 mm, 100 Å) and three PSS Suprema (300 x 8 mm, 100 Å) columns. Each measurement was conducted at a flow rate of 1 mL/min. and an injection volume of 20 μL was chosen. A Na_2HPO_4 buffer solution (pH 12) with 0.5 g PEG 6000 was used as solvent, and the signals were detected with an ECO Sec RI and/or UV-detector. The elugrams below show the detector response of the RI-detector.

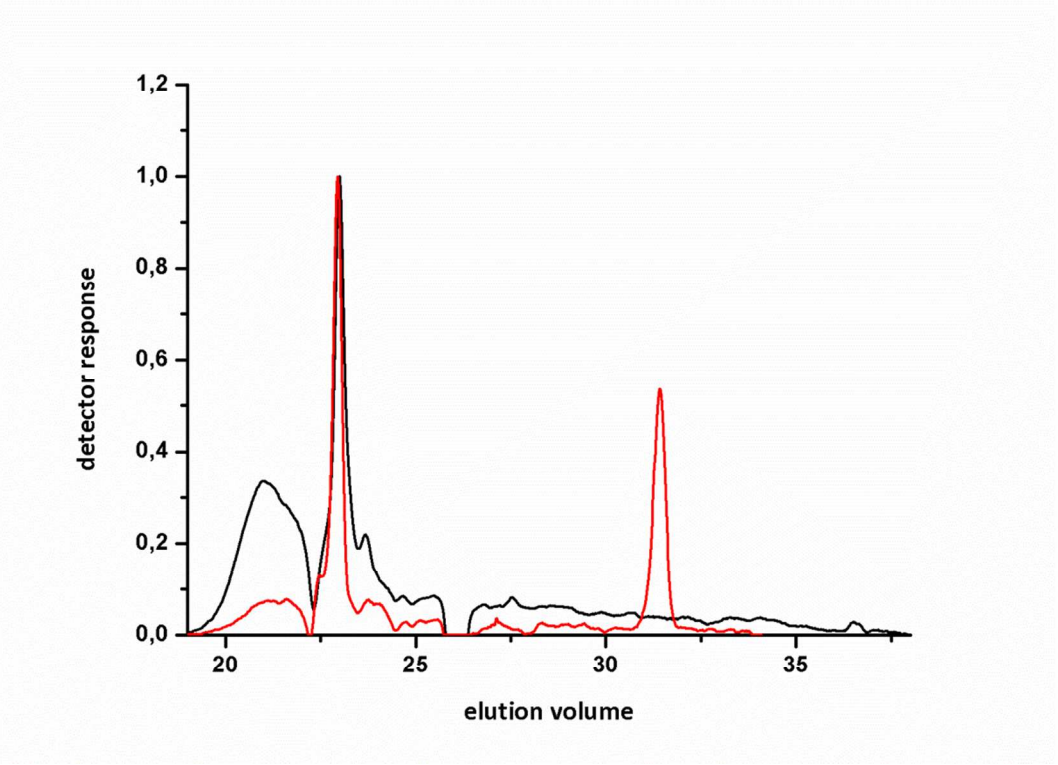


Figure S7: GPC elugram of the kraft-lignin sample A before (black line) and after (red line) the reaction.

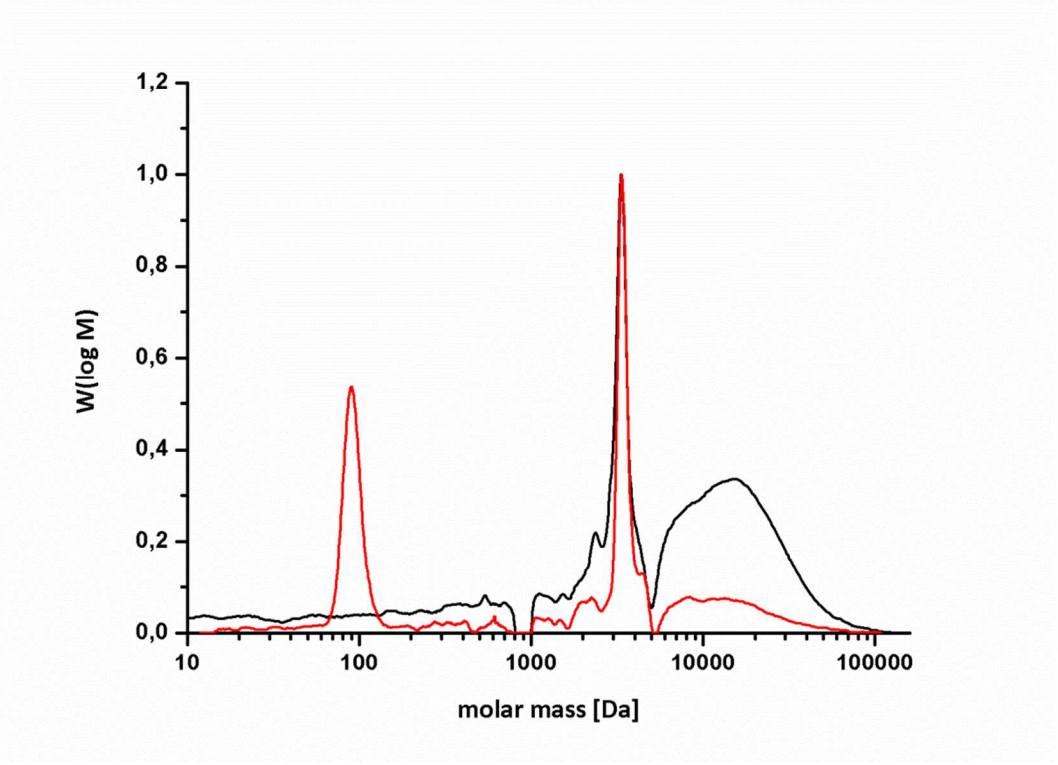


Figure S8: GPC molar mass distribution of the kraft-lignin sample A before (black line) and after (red line) the reaction.

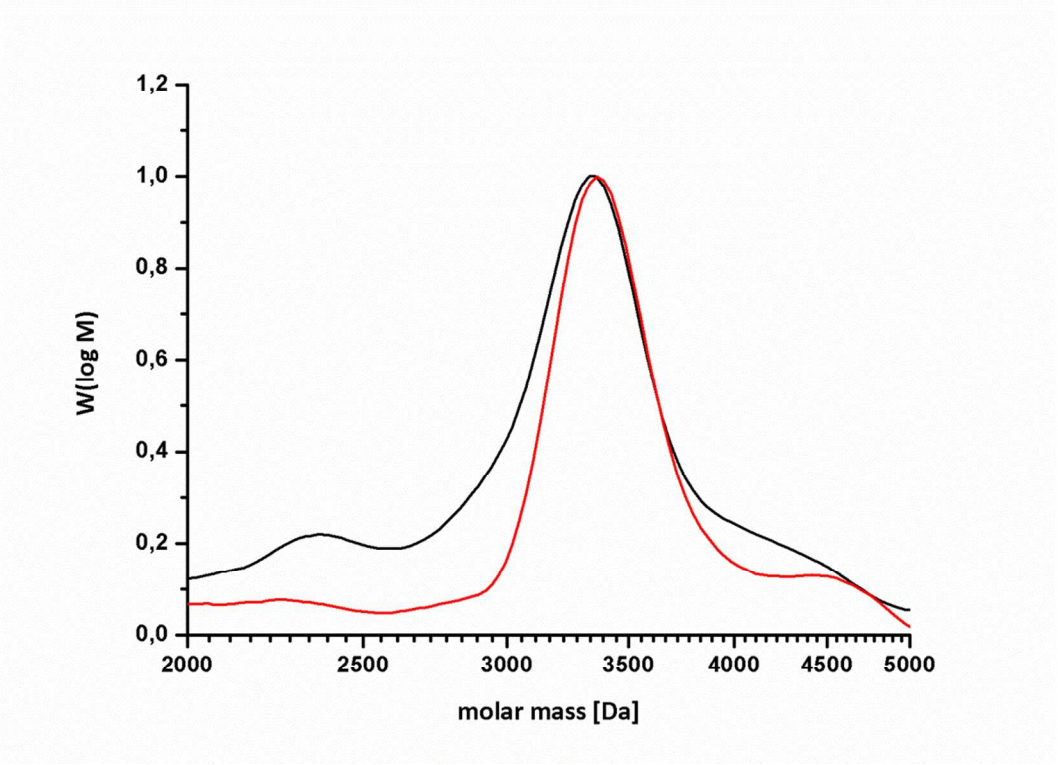


Figure S9: Detailed view on the GPC molar mass distribution of the kraft-lignin sample A before (black line) and after (red line) the reaction in the range between 2000-5000 Da.

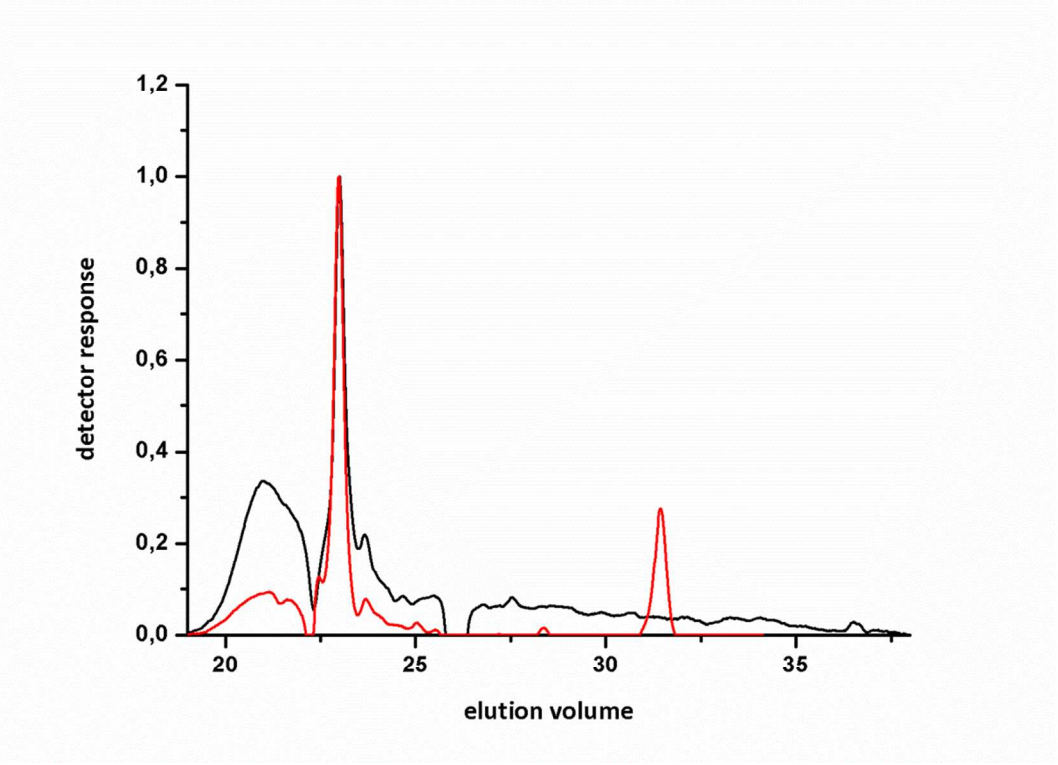


Figure S10: GPC elugram of the organosolv-lignin sample B before (black line) and after (red line) the reaction.

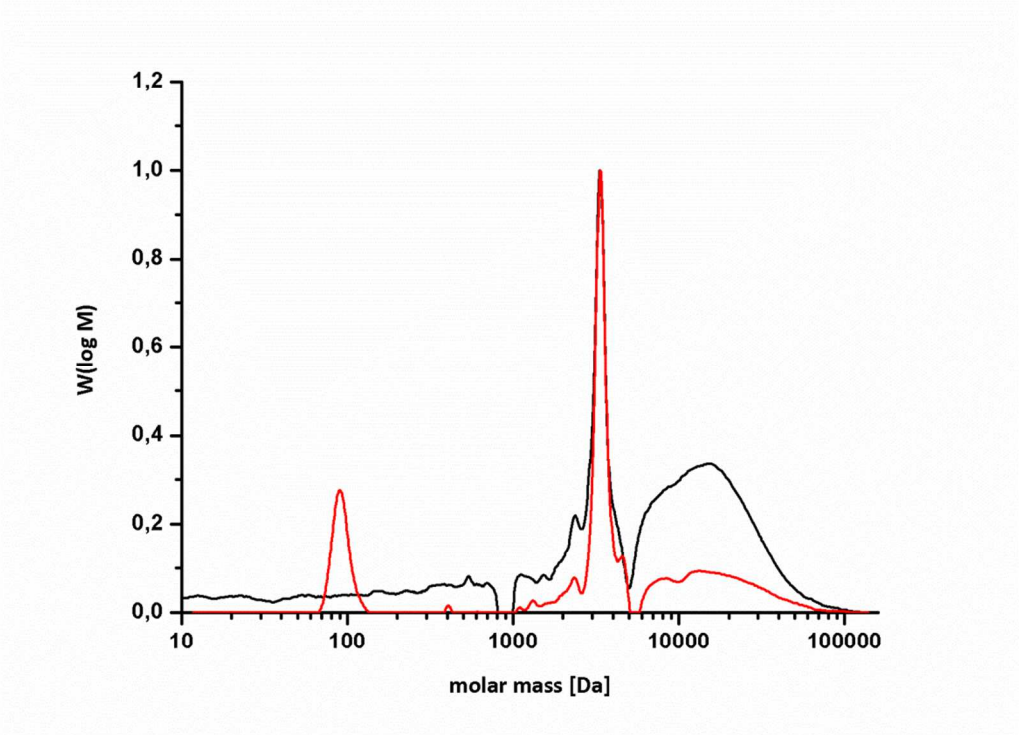


Figure S11: GPC molar mass distribution of the organosolv-lignin sample B before (black line) and after (red line) the reaction.

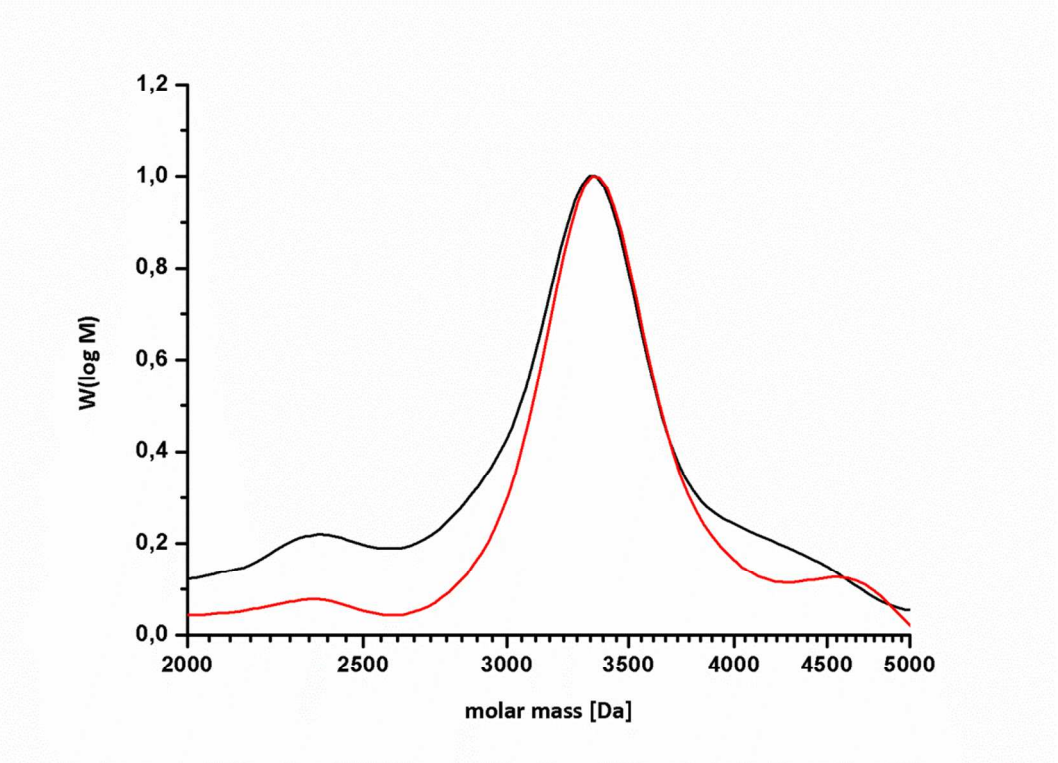
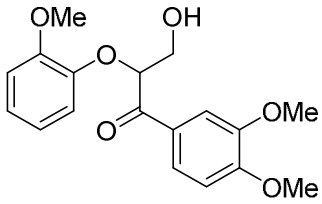


Figure S12: Detailed view on the GPC molar mass distribution of the organosolv-lignin sample B before (black line) and after (red line) the reaction in the range between 2000-5000 Da.

6. Spectroscopic data of the isolated products

1-(3,4-Dimethoxyphenyl)-3-hydroxy-2-(2-methoxyphenoxy)propan-1-one (2a)



$C_{18}H_{20}O_6$ (332.35 g/mol)

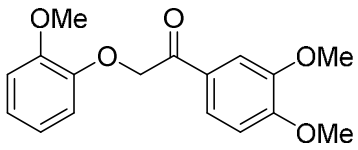
^{1}H NMR (600 MHz, ($CDCl_3$)): δ = 7.75 (dd, *J* = 8.4, 1.9 Hz, 1H), 7.62 (d, *J* = 1.9 Hz, 1H), 7.00 (td, *J* = 7.9, 1.4 Hz, 1H), 6.93–6.87 (m, 3H), 6.82 (td, *J* = 7.9, 1.2 Hz, 1H), 5.40 (t, *J* = 5.3 Hz, 1H), 4.07 (d, *J* = 5.3 Hz, 2H), 3.95 (s, 3H), 3.92 (s, 3H), 3.86 (s, 3H).

^{13}C NMR (151 MHz, ($CDCl_3$)): δ = 195.0, 153.9, 150.5, 149.2, 146.9, 128.0, 123.7, 123.6, 121.2, 118.5, 112.2, 110.9, 110.1, 84.6, 63.7, 56.1, 56.0, 55.8.

MS (EI, 70 eV): m/z (%): 333 (44) $[M+1]^+$, 332 (75) $[M]^+$, 315 (28), 182 (23), 166 (21), 165 (100), 150 (57), 137 (10).

The spectral data corresponds to the one reported in literature.[2]

1-(3,4-Dimethoxyphenyl)-2-(2-methoxyphenoxy)ethan-1-one (2b)



$C_{17}H_{18}O_5$ (302.33 g/mol)

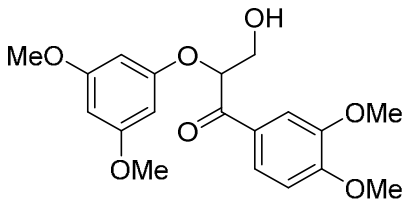
^{1}H NMR (400 MHz, ($CDCl_3$)): δ = 7.67 (dd, *J* = 8.4, 2.0 Hz, 1H), 7.59 (d, *J* = 2.0 Hz, 1H), 6.96–6.84 (m, 5H), 5.28 (s, 2H), 3.94 (s, 3H), 3.93 (s, 3H), 3.88 (s, 3H).

^{13}C NMR (101 MHz, ($CDCl_3$)): δ = 193.4, 153.9, 149.8, 149.3, 147.7, 128.0, 122.9, 122.5, 120.9, 114.8, 112.3, 110.6, 110.3, 72.2, 56.2, 56.1, 56.0.

MS (EI, 70 eV): m/z (%): 303 $[M+1]^+$ (10), 302 $[M]^+$ (53), 165 (100), 151 (11), 77 (14), 51 (11).

The spectral data corresponds to the one reported in literature.[2]

2-(3,5-Dimethoxyphenoxy)-1-(3,4-dimethoxyphenyl)-3-hydroxypropan-1-one (2c)



$C_{19}H_{22}O_7$ (362.38 g/mol)

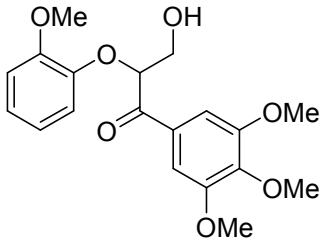
^{1}H NMR (600 MHz, ($CDCl_3$)): δ = 7.70 (dd, *J* = 8.4, 1.9 Hz, 1H), 7.50 (d, *J* = 1.9 Hz, 1H), 6.82 (d, *J* = 8.4 Hz, 1H), 6.01 (m, 2H), 5.47 (dd, *J* = 6.2, 4.1 Hz, 1H), 5.24 (s, 1H), 4.06 (m, 2H), 3.87 (s, 3H), 3.82 (s, 3H), 3.63 (s, 6H), 3.02 (bs, 1H).

^{13}C NMR (151 MHz, ($CDCl_3$)): δ = 194.9, 161.5 (2C), 159.2, 154.0, 149.2, 127.7, 123.5, 110.8, 110.2, 94.1 (2C), 93.8, 80.8, 63.4, 56.0, 55.9, 55.2 (2C).

MS (EI, 70 eV): m/z (%): 362 $[M]^+$ (24), 180 (37), 166 (17), 165 (100), 155 (12), 77 (12).

The spectral data corresponds to the one reported in literature.[2]

3-Hydroxy-2-(2-methoxyphenoxy)-1-(3,4,5-trimethoxyphenyl)propan-1-one (2d)



$C_{19}H_{22}O_7$ (362.38 g/mol)

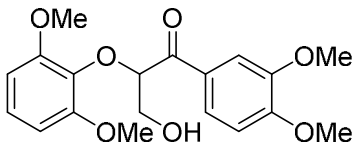
^{1}H NMR (600 MHz, ($CDCl_3$)): δ = 7.36 (s, 2H), 7.03–6.99 (m, 1H), 6.94–6.88 (m, 2H), 6.86–6.81 (m, 1H), 5.35 (t, *J* = 5.3 Hz, 1H), 4.10–4.08 (m, 2H), 3.92 (s, 3H), 3.87 (s, 6H), 3.85 (s, 3H).

^{13}C NMR (151 MHz, ($CDCl_3$)): δ = 195.7, 153.2 (2C), 150.5, 146.9, 143.4, 130.1, 123.8, 121.3, 118.3, 112.4, 106.6 (2C), 84.7, 63.7, 61.1, 56.4 (2C), 55.9.

MS (EI, 70 eV): *m/z* (%): 362 (10) $[M]^+$, 332 (25), 222 (12), 195 (100), 150 (10), 109 (11), 77 (18).

The spectral data corresponds to the one reported in literature.[4]

2-(2,6-Dimethoxyphenoxy)-1-(3,4-dimethoxyphenyl)-3-hydroxypropan-1-one (2e)



$C_{19}H_{22}O_7$ (362.38 g/mol)

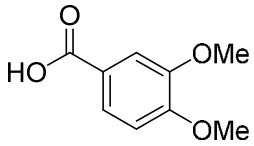
^{1}H NMR (600 MHz, ($CDCl_3$)): δ = 7.69 (dd, *J* = 8.4, 1.8 Hz, 1H), 7.63 (d, *J* = 1.8 Hz, 1H), 6.98 (t, *J* = 8.4 Hz, 1H), 6.85 (d, *J* = 8.4 Hz, 1H), 6.54 (d, *J* = 8.4 Hz, 2H), 5.07 (dd, *J* = 7.8, 3.6 Hz, 1H), 4.01–3.92 (m, 2H), 3.91 (s, 3H), 3.91 (s, 3H), 3.83–3.77 (m, 1H), 3.69 (s, 6H).

^{13}C NMR (151 MHz, ($CDCl_3$)): δ = 194.9, 153.4, 152.7 (2C), 149.0, 136.6, 128.6, 124.3, 123.4, 110.8, 110.0, 105.2 (2C), 87.4, 63.6, 56.0 (2C), 55.9 (2C).

MS (EI, 70 eV): m/z (%): 363 (12) $[M+1]^+$, 362 (43) $[M]^+$, 180 (44), 166 (10), 165 (100), 154 (43), 153 (21), 151 (13).

The spectral data corresponds to the one reported in literature.[2]

3,4-Dimethoxybenzoic acid (3a)



$C_9H_{10}O_4$ (182.18 g/mol)

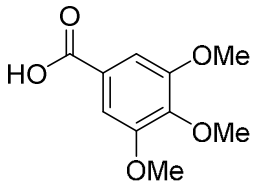
^{1}H NMR (400 MHz, ($CDCl_3$)): δ = 10.31 (bs, 1H), 7.77 (dd, *J* = 8.4, 1.9 Hz, 1H), 7.59 (d, *J* = 1.8 Hz, 1H), 6.89 (d, *J* = 8.4 Hz, 1H), 3.94 (s, 3H), 3.93 (s, 3H).

^{13}C NMR (101 MHz, ($CDCl_3$)): δ = 171.9, 153.5, 148.7, 124.6, 112.5, 110.4 (2C), 56.1, 56.0.

MS (EI, 70 eV): m/z (%): 183 $[M+1]^+$ (13), 182 $[M]^+$ (100), 167 (25), 111 (13), 51 (13).

The spectral data corresponds to the one reported in literature.[6]

3,4,5-Trimethoxybenzoic acid (3b)



$C_{10}H_{12}O_5$ (212.20 g/mol)

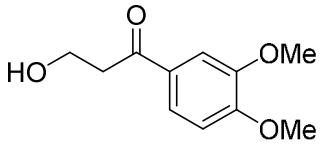
^{1}H NMR (600 MHz, ($CDCl_3$)): δ = 12.1 (bs, 1H), 7.36 (s, 2H), 3.93 (s, 3H), 3.92 (s, 6H).

^{13}C NMR (151 MHz, ($CDCl_3$)): δ = 171.0, 153.1, 143.0, 124.2, 107.5 (2C), 61.1, 56.4 (3C).

MS (EI, 70 eV): *m/z* (%): 212 (100) $[M]^+$, 195 (48), 169 (23), 141 (34), 111 (21), 93 (18), 66 (11).

The spectral data corresponds to the one reported in literature.[7]

1-(3,4-Dimethoxyphenyl)-3-hydroxypropan-1-one (4)



$C_{11}H_{14}O_4$ (210.23 g/mol)

^{1}H NMR (400 MHz, ($CDCl_3$)): δ = 7.59 (dd, *J* = 8.4, 2.0 Hz, 1H), 7.53 (d, *J* = 2.0 Hz, 1H), 6.90 (d, *J* = 8.4 Hz, 1H), 4.02 (t, *J* = 5.3 Hz, 2H), 3.96 (s, 3H), 3.94 (s, 3H), 3.20 (t, *J* = 5.3 Hz, 2H).

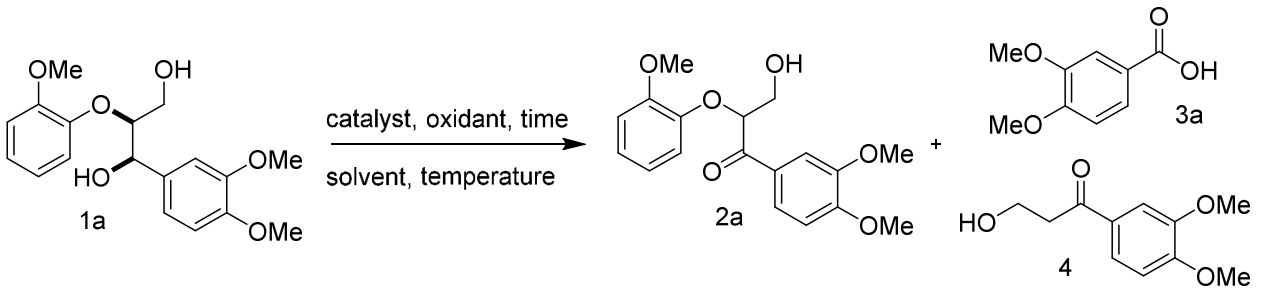
^{13}C NMR (101 MHz, ($CDCl_3$)): δ = 199.1, 153.6, 149.1, 129.9, 123.0, 110.0, 109.8, 58.3, 56.1, 56.0, 39.8.

MS (EI, 70 eV): *m/z* (%): 210 (23) $[M]^+$, 167 (14), 166 (12), 165 (100), 150 (10), 95 (12).

The spectral data corresponds to the one reported in literature.[4]

7. Screening parameters for the Co-catalyzed oxidation of dilignol 1a

Table S1: Optimization of the reaction conditions for the catalytic cleavage of dilignol 1a.[a]



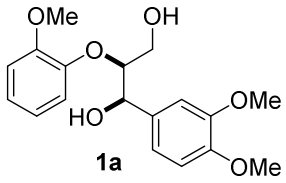
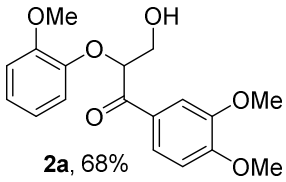
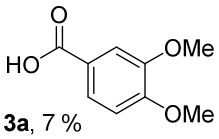
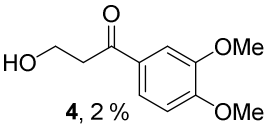
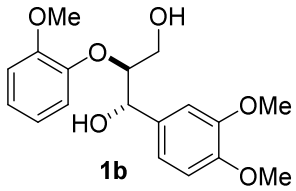
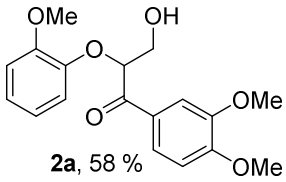
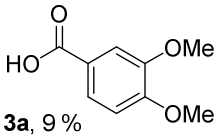
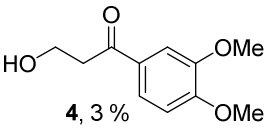
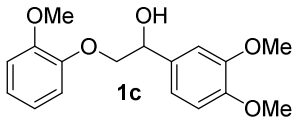
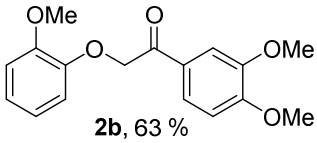
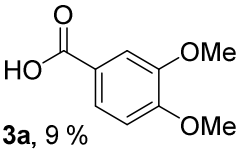
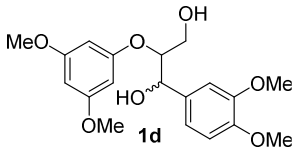
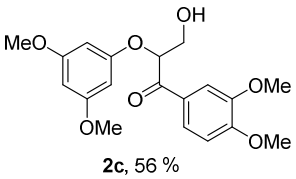
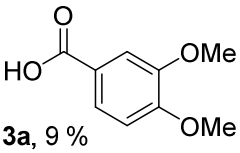
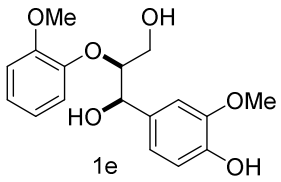
Entry	Catalyst	Oxidant	Time [h]	Temperature [°C]	Solvent	Conv. [%][b]	Product [%] 2a[b]	3a[b]	4[b]
1[c,d]	$Co(acac)_3$	NHPI – O_2	16	100	AcOH	88	-	-	-
2[c]	$Co(acac)_3$	NHPI – O_2	16	100	H_2O	35	-	-	-
3[c]	$Co(acac)_3$	NHPI – O_2	16	100	THF	30	6	-	-
4[c]	$Co(acac)_3$	NHPI – O_2	16	100	toluene	43	18	-	-
5[c]	$Co(acac)_3$	NHPI – O_2	16	100	DMSO	21	1	-	-
6[c]	$Co(acac)_3$	NHPI – O_2	16	100	DMF	27	5	-	-
7[c]	$Co(acac)_3$	NHPI – O_2	16	100	acetonitrile	15	13	-	-
8[c]	$Co(acac)_3$	NHPI – O_2	16	100	pyridine	13	9	-	-
9[c]	$Co(acac)_3$	NHPI – O_2	16	100	dioxane	72	63	4	-
10	$Co(acac)_3$	NHPI – O_2	16	rt	dioxane	3	-	-	-
11	$Co(acac)_3$	NHPI – O_2	16	40	dioxane	6	1	-	-
12	$Co(acac)_3$	NHPI – O_2	16	60	dioxane	10	6	-	-
13	$Co(acac)_3$	NHPI – O_2	16	80	dioxane	95	63	9	-
14	$Co(acac)_3$	NHPI – O_2	16	90	dioxane	94	49	11	-
15	$Co(acac)_3$	NHPI – O_2	16	110	dioxane	>99	35	26	-
16	$Co(acac)_3$	NHPI – O_2	16	120	dioxane	>99	10	25	-
17	$Co(acac)_3$	NHPI – O_2	16	135	dioxane	>99	2	29	-
18[c]	$Co(acac)_3$	NHPI – O_2	16	80	dioxane	70	52	6	-
19[c]	$Co(acac)_3$	NHPI – air	16	80	dioxane	18	10	-	-
20	$Co(acac)_3$	O_2	16	80	dioxane	8	1	-	-
21	-	NHPI – O_2	16	80	dioxane	9	7	-	-
22	-	O_2	16	80	dioxane	-	-	-	-
23[c]	$Co(acac)_3$	NHPI – argon	16	80	dioxane	9	6	-	-
24[e]	$Co(acac)_3$	NHPI – O_2	16	80	dioxane	91	65	6	-
25[f]	$Co(acac)_3$	NHPI – O_2	16	80	dioxane	88	62	9	-
26[g]	$Co(acac)_3$	NHPI – O_2	16	80	dioxane	92	68	7	2
27	$Co(acac)_3$	NHPI – O_2	1	80	dioxane	-	-	-	-
28	$Co(acac)_3$	NHPI – O_2	2	80	dioxane	7	3	-	-
29	$Co(acac)_3$	NHPI – O_2	4	80	dioxane	12	3	1	-
30	$Co(acac)_3$	NHPI – O_2	6	80	dioxane	63	50	5	-
31	$Co(acac)_3$	NHPI – O_2	8	80	dioxane	84	60	5	-

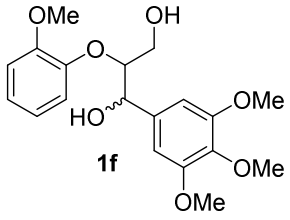
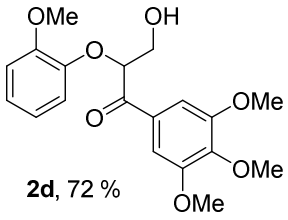
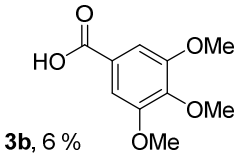
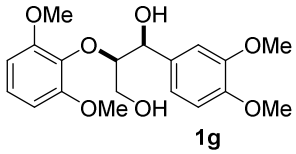
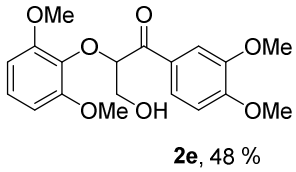
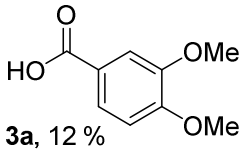
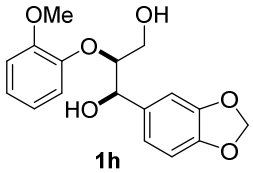
32	$Co(acac)_3$	NHPI – O_2	12	80	dioxane	86	62	8	-
33	$Co(acac)_3$	NHPI – O_2	24	80	dioxane	95	67	9	-
34	0.5 mol% $Co(acac)_3$	NHPI – O_2	16	80	dioxane	85	51	4	-
35	5 mol% $Co(acac)_3$	NHPI – O_2	16	80	dioxane	97	44	10	-
36	$Co(acac)_3$	5 mol% NHPI – O_2	16	80	dioxane	47	31	-	-
37	$Co(acac)_3$	50 mol% NHPI – O_2	16	80	dioxane	95	79	9	-
38	2 mol% Co_3O_4	NHPI – O_2	16	80	dioxane	33	25	-	-
39	$Co(NO_3)_2$	NHPI – O_2	16	80	dioxane	50	22	-	-
40	$Co(OAc)_2$	NHPI – O_2	16	80	dioxane	57	15	-	-
41	$CuCl_2$	NHPI – O_2	16	80	dioxane	60	44	-	-
42	$FeCl_2$	NHPI – O_2	16	80	dioxane	>99	25	3	-
43[h]	$Co(acac)_3$	NHPI – O_2	16	80	dioxane	27	-	8	-
44[i]	$Co(acac)_3$	NHPI – O_2	16	80	dioxane	-	-	-	-
45[j]	$Co(acac)_3$	NHPI – O_2	16	80	dioxane	-	-	-	-

[a] Reaction conditions: **1a** (0.25 mmol), catalyst [1 mol%], oxidant [10 mol%] – O_2 [5 bar], 1 mL solvent, in a 25 mL glass autoclave; [b] yields and conversion determined by HPLC with 3,4-dimethoxybenzyl alcohol as internal standard and given in mole basis; [c] reaction performed in a 25 mL flask with 1 atm oxygen pressure (balloon); [d] formation of the mono- and di-acetylation products of **1a**; [e] 2.5 bar O_2; [f] 7 bar O_2; [g] conversion and yield after column chromatography on 1 mmol scale; [h] use of ketone **2** as starting material; [i] use of 3,4-dimethoxy benzaldehyde as starting material; [j] use of acid **3** as starting material.

8. Product distribution for the oxidation of different β-O-4 lignin model compounds

Table S2: Overview on the formed products in the Co-catalyzed oxidation of different dilignol type model compounds.[a]

Entry	Substrate	Yield ketone product **2** [%]	Yield acid product **3** [%]	Yield alcohol product **4** [%]
1	 **1a**	 **2a**, 68%	 **3a**, 7 %	 **4**, 2 %
2	 **1b**	 **2a**, 58 %	 **3a**, 9 %	 **4**, 3 %
3	 **1c**	 **2b**, 63 %	 **3a**, 9 %	-
4	 **1d**	 **2c**, 56 %	 **3a**, 9 %	-
5	 1e	-	-	-

6	 **1f**	 **2d**, 72 %	 **3b**, 6 %	-
7	 **1g**	 **2e**, 48 %	 **3a**, 12 %	-
8	 **1h**	-	-	-

[a] Reaction conditions: **1** (1.0 mmol), $Co(acac)_3$ (0.01 mmol, 1 mol%.), NHPI (0.1 mmol, 10 mol%), dioxane (4 mL), 5 bar O_2, 80 °C, 16 h; yields after column chromatography and given in mole basis.

9. References

[1] Buendia, J.; Mottweiler, J.; Bolm, C. Preparation of Diastereomerically Pure Dilignol Model Compounds. *Chem. Eur. J.* **2011**, *17*, 13877–13882.

[2] Picart, P.; Müller, C.; Mottweiler, J.; Wiermans, L.; Bolm, C.; Domínguez de María, P.; Schallmey, A. From Gene Towards Selective Biomass Valorization: Bacterial β-Etherases with Catalytic Activity on Lignin-Like Polymers. *ChemSusChem* **2014**, *7*, 3164–3171.

[3] Rahimi, A.; Azarpira, A.; Kim, H.; Ralph, J.; Stahl, S. S. Chemoselective Metal-Free Aerobic Alcohol Oxidation in Lignin. *J. Am. Chem. Soc.* **2013**, *135*, 6415–6418.

[4] Lancefield, C. S.; Ojo, O. S.; Tran, F.; Westwood, N. J. Isolation of Functionalized Phenolic Monomers through Selective Oxidation and C–O Bond Cleavage of the β-O-4 Linkages in Lignin. *Angew. Chem. Int. Ed.* **2015**, *54*, 258–262; Lancefield, C. S.; Ojo, O. S.; Tran, F.; Westwood, N. J. *Angew. Chem.* **2015**, *127*, 260–264.

[5] Kleine, T.; Buendia, J.; Bolm, C. Mechanochemical degradation of lignin and wood by solvent-free grinding in a reactive medium. *Green Chem.* **2013**, *15*, 160–166.

[6] Mottweiler, J.; Puche, M.; Räuber, C.; Schmidt, T.; Concepción, P.; Corma, A.; Bolm, C. Copper- and Vanadium-Catalyzed Oxidative Cleavage of Lignin using Dioxygen. *ChemSusChem* **2015**, *8*, 2106–2113.

[7] Terazzi, E.; Torelli, S.; Bernardinelli, G.; Rivera, J.-P.; Benech, J.-M.; Bourgogne, C.; Donnio, B.; Guillon, D.; Imbert, D.; Bunzli, J.-C. G.; Pinto, A.; Jeannerat, D.; Piguet, C. Molecular Control of Macroscopic Cubic, Columnar, and Lamellar Organizations in Luminescent Lanthanide-Containing Thermotropic Liquid Crystals. *J. Am. Chem. Soc.* **2005**, *127*, 888–903.